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ScienceDirect
Catena 71 (2007) 477–486
CATENA
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Paleosols from the groups of burial mounds provide paleoclimatic records of centennial to intercentennial time scale: A case study from the Early Alan cemeteries in the Northern Caucasus (Russia)

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Abstract

Buried soil chronosequences under a series of Early Alan kurgans (burial mounds) in the Vladikavkazkaya depression of the Northern Caucasus, Russia, were studied to derive a high-resolution paleoclimatic record from the variations of the selected paleosol properties. Haplic Chernozems occur under kurgans and on the actual land surface. Three kurgan cemeteries, Brut 1, Brut 2 and Beslan, dated from the end of the second to the beginning of the seventh centuries AD have been studied. The cemeteries are situated close to each other under similar lithological and geomorphological conditions but differed in the paleosols' preservation. The Brut 2 site has been recently altered due to annual ploughing and intensive irrigation for more than 30 years. The background soils and paleosols of the Brut 2 site have been compared with synchronous soils of non-irrigated Brut 1 and Beslan sites to detect pedogenic properties that are less changed by irrigation and thus comprise the "soil memory". Stronger black color of humus horizon, increase of humus content and decrease of humus $\delta^{13}C$ values; clear signs of biological activity, absence of morphological and analytical signs of solonetz properties; diffused carbonate white soft spots in the Bca horizon and decreasing carbonate content are thought to be related to the comparatively humid climatic conditions in the region. On the contrary, relatively low humus content, tongue-like lower boundary of humus horizon, increase of humus $\delta^{13}C$ values, morphological signs of solonetz properties together with high content of exchangeable Na, relatively large and clearly shaped carbonate white soft spots in the paleosols of the Brut 2 site, as well as increase of density, thickness of the carbonate pseudomicellium and high carbonate content in the upper part of profiles in the paleosols of the non-irrigated Brut 1 site are assumed to be xeromorphic features, indicating comparatively drier climatic conditions. The paleosols of the earliest chronointerval of burial (the end of the second to the beginning of the third centuries AD) demonstrate clear xeromorphic properties which indicate a relatively dry climate with a mean annual precipitation 50–100 mm less than today. The estimated duration of the period with such climatic conditions is thought to be not less than 100 years. In addition, those paleosols have some weak signs of humid conditions indicating that between the end of the first and the middle of the second centuries AD the climate was getting more moist, mean annual precipitation became equal or slightly higher than today. The paleosols buried in the first half of the fifth century AD again demonstrate the gradual enhancement of xeromorphic properties reflecting the next stage of droughts. Thus, the period with favourable humid climate when the Early Alan culture flourished in the Northern Caucasus was relatively short (about 400 years). Studying the detailed chronosequence in the non-irrigated Brut 1 site the records of intercentennial time scale soil properties variability produced by comparatively "fast" pedogenic processes typical for the steppe zone i.e., humus formation and accumulation, bioturbation, carbonate accumulation and transformation and solonetzization, have been provided.

Keywords: Irrigation; Paleosols; Soil evolution; Kurgans; Paleoclimatic reconstruction; Holocene; Early Alan Culture; Northern Caucasus

1. Introduction

Investigations of paleosols buried under archaeological monuments in the steppe area are widely carried out in Russia nowadays. The overwhelming majority of such studies are devoted to the examination of paleosols beneath kurgans (burial

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doi:10.1016/j.catena.2007.03.013

mounds, ramparts). The properties of paleosols buried under kurgans are generally thought to be unaltered by ancient human activity; hence they may represent a proxy for paleoenvironmental conditions over the epochs prior to their burial (Ivanov, 1978; Ivanov and Alexandrovskiy, 1984; Alexandrovskiy, 1996). Recently the ancient human impact on the paleosols before their burial have been considered. Sometimes, human-affected properties of paleosols are not detected by the traditional morphogenetic analysis of their profiles and that could influence the accuracy of their paleoenvironmental interpretation (Alexandrovskiy et al., 1997; Gol'eva, 2000; Spiridonova et al., 2001; Gol'eva and Khokhlova, 2004). Some papers were devoted to the diagenetic changes of paleosols which occurred after their burial as a result of natural processes developed beneath earth piles of kurgans (Gubin, 1984; Khokhlova et al., 2000; Alexandrovskiy et al., 2004).

In addition, there is another aspect of the impact on paleosols buried under kurgans that has not been practically examined in archaeological pedology. It is the case when the change of paleosol properties together with kurgan mounds results from modern agricultural activity. In this case, to extract the paleoenvironmental signal from paleosols it is necessary to distinguish the initial properties that existed in them before burial and the actual ones that appeared as a result of modern agrogenic impact.

Moreover, one of the most discussed problems of the study of paleosols buried under kurgans is the temporal resolution of the paleopedological record. In our opinion, studying a detailed chronosequence with short intervals between the dates of soils burial it is possible to reveal the intercentennial time-scale of variability of pedogenetic properties and related changes of paleoenvironmental conditions.

Hence, our work is aimed at (1) revealing the initial properties of paleosols buried under kurgans which have been recently influenced by the intensive agrogenic impact; (2) understanding the properties of paleosols that have intercentennial time scale of variability; (3) reconstructing the paleoclimatic conditions for different chronointervals over the period of development of the Early Alan Culture in the Northern Caucasus, Russia, using the initial properties of the paleosols buried under kurgans.

2. Materials and methods

The paleopedological study of kurgans constructed by the Early Alan people between the second and the middle of the fifth centuries AD near Brut village in the Northern Ossetiya–Alaniya Republic, Russia was carried out by the Northern Ossetin expedition of the Institute of Archaeology RAS and the Museum of Oriental Art in 2002–2004. The study site is located within the Ossetinskaya (or Vladikavkazkaya) alluvial depression formed by sediments of the Terek and Sunzha Rivers and their tributaries. One of the latter is the Kambileevka River in the valley of which the study site is located (Fig. 1). Mountain ridges of the Big Caucasus at the south, east and north surround the depression. The climate is typical of the semiarid steppe zone: mean annual temperature is 8.4 °C, the hottest month is July with monthly mean temperature +20.6 °C, the coldest month is January: −4.4 °C. The mean annual precipitation is about 600 mm, of which 350–500 mm falls during the period of active plant growth. However, evaporation is fairly intense and the coefficient of evaporation is about 0.7. The Ordinary Chernozems (Soil nomenclature in Russian and foreign languages, 1974) or Haplic Chernozems with medium to thick

Fig. 1. Map of the research area. Arrow shows the location of the study site near Brut village in the Northern Ossetiya–Alaniya Republic.

humus horizons and different contents of carbonates predominate in modern soil cover of the region and are buried under the kurgans studied. The soil parent materials are pale yellow and yellowish-brown loess-like loams (Val'kov, 1977; Nature and natural resources of central and eastern parts of the Northern Caucasus, 1982; Natural conditions and resources of the Northern Caucasus, 1986).

The paleosols of ancient cemeteries Brut 1, Brut 2 and Beslan have been studied. The cemeteries studied were located in the vicinity to each other with identical lithological and geomorphological conditions (the first terrace of the Kambileevka River) and differed only with respect to the conditions of the paleosols' conservation. The Brut 2 site is within the agricultural field that had been intensively irrigated for more than 30 years during approximately 1960–1990, then irrigation was completely stopped. The irrigation rate of those years was 300–400 mm per growing period, and, in fact, the soil moisture regime was changed under irrigation from natural non-leaching moisture regime to a leaching one (Antykov and Stomorev, 1970). Before irrigation, the field was obviously leveled, hence, the burial mounds were leveled. In addition, the field is annually ploughed up until nowadays, and to the moment of our work the mounds of kurgans were very thin (10–20–40 cm). According to the Soil Taxonomy (Soil Survey Staff, 1994) soils buried under mounds thinner than 50 cm cannot be considered as paleosols since their safe preservation from environmental influence is not guaranteed. In the Brut 2 cemetery kurgans not only had thin mounds but were under intensive agrogenic impact such as the irrigation. At that, the Brut 2 site had the most diversity of paleosol burial chronointervals over time of the Early Alan Culture development.

The paleosols of other burial grounds Brut 1 and Beslan were safely buried under thick kurgan mounds. Fig. 2 indicates the mound and paleosol of the Big Beslansky kurgan. The surface (background) soils of these two sites are within the plowed but non-irrigated field (Beslan) or non-arable pasture (Brut 1). This allows us to use the background soils and buried paleosols of these two cemeteries as an indicator for the grade of preservation of initial properties of paleosols and background soils of the Brut 2 site. The main methodological approach of our study consisted in a comparative analysis of the background soils and buried paleosols of the same chronointervals of burial in the non-irrigated Brut 1 and Beslan sites with those in the Brut 2 site. The list of the studied kurgans and soil pits and the dates of kurgans' construction determined archaeologically (with maximal precision acquired for the East European chronology of the Roman Time) are presented in Table 1. The numbers of the kurgans and soil pits studied are arbitrary and were assigned according to the order of their study in the field by archaeologists (numbers of kurgans) and pedologists (numbers of soil pits). The letter "b" in a pit number means that we studied a buried soil, "m" — a modern background soil.

22 pits of paleosols buried under kurgans and background soils situated close to kurgans were described and sampled in the field. The morphological patterns of all the soil profiles studied are presented in Table 2. The content of humus was determined according to the Tyurin method, carbonate CO_2 acidimetrically, gypsum SO_4 and exchangeable Na by routine methods (Arinushkina, 1970). The original humus content (before post-burial losses) in all the paleosols was reconstructed according to the approach by Ivanov (1992). The data of humus content obtained for paleosols was multiplied by 2 to get initial humus content. The ratio of stable isotopes $^{13}C/^{12}C$ was measured for soil/paleosol organic matter. For these measurements the Delta PlusXL mass-spectrometer with a precision ±0.1‰ was used. To determine the carbon isotopic composition of humus, soil samples were treated by HCl to remove carbonates. The soil samples were combusted in the Costech elemental analyzer. The $\delta^{13}C$ (‰) results were given relative to the PDB standards.

3. Results and discussion

The chronointervals of the paleosols' burial in the archaeological sites Brut 1, 2 and Beslan overlap in some cases (Table 1). The paleosol buried under the Big Beslansky kurgan (BBK, p.29b/03) that has been widely dated as the third century AD may be compared with the paleosols of the Brut 2 cemetery buried at about the same time — kurgans NN 2, 4, 7, 10, pits NN 24b/02, 20b/02, 26b/02, 27b/03, respectively. The dates of construction of the kurgan N13 in the Brut 1 cemetery and of the kurgan N9 in the Brut 2 site are rather similar and referred to the

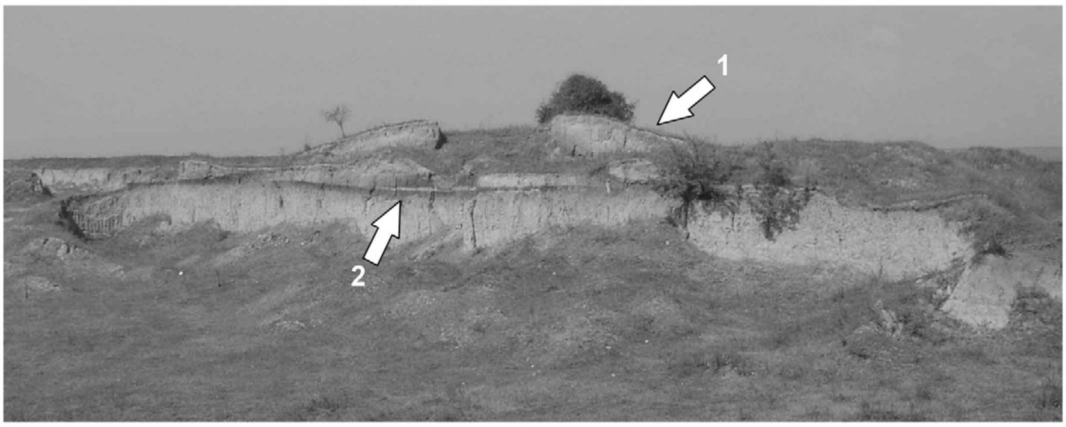

Fig. 2. The Big Beslansky kurgan. Arrow 1 shows the kurgan mound of 6 m thickness; arrow 2 shows the paleosol beneath the kurgan mound.

Table 1
Objects of investigations

Soil pit	Kurgan	Thickness of kurgan mound, cm	Archaeological dates of kurgan construction and paleosol burial
The kurgan site Brut 2			
25b/02	3	42	The end of the second–the beginning of the third centuries AD
23m/02, background soil near kurgan N3			
22b/02*	1	<10	The end of the second–the beginning of the third centuries AD
21b/02	5	50	The end of the second–the beginning of the third centuries AD**
24b/02*	2	<10	The beginning of the third century AD
20b/02	4	20	The beginning of the third century AD
27b/03	10	40	The beginning of the third century AD
26b/02*	7	<20	The middle of the second–the middle of the third centuries AD
28b/03	9	30	The approximate border between the fourth and fifth centuries AD
31b/03	18	40–45	The last quarter of the sixth–the beginning of the seventh centuries AD
The kurgan site Beslan			
29b/03	Big Beslansky kurgan (BBK)	~600	The third century AD
30m/03, background soil near BBK			
The kurgan site Brut 1			
13b/04	13	60	The approximate border between fourth and fifth centuries AD
2b/04*	2	100	The first half of the fifth century AD
10b/04	10	60	The first half of the fifth century AD
11b/04	11	55	The first half of the fifth century AD
9b/04	9	90	The first half of the fifth century AD
8m/04, background soil near kurgan N9			
32b/03*	7	80	The first half of the fifth century AD
34m/03*, background soil near kurgan N7			
12b/04	12	60–65	The first half of the fifth century AD
14b/04	14	55	The first half of the fifth century AD

Pits with sign (*) have been studied morphologically only, without sampling.
Sign (**) means that the date of kurgan N5 construction has not been determined archaeologically but has been suggested based on near resemblance of the paleosols buried under kurgans NN 1, 3 and 5.

approximate border between fourth and fifth centuries AD (Table 1).

The morphological analysis of the paleosol buried under BBK (p.29b/03) and the background soil (p.30m/03) in the Beslan site demonstrates their differences from the soils of the Brut 2 site on the whole. In the soils of the Beslan site the humus horizon was darker and the carbonate horizon contained a greater diversity of carbonate accumulations than those in the soils of the Brut 2 site. There were even pseudomicellar forms of carbonate in the soils of the Beslan site. It has been previously shown by us (Khokhlova et al., 1997) that those forms of carbonate are very mobile and disappear from the Chernozems under irrigation first and rather quickly (less than after 30 years of irrigation how in the case study). Sometimes, in the paleosols of Brut 2 we were able to observe the morphons (small patches within soil horizon) with well preserved carbonate white soft spots which had sharper boundaries with soil mass and a larger size than such carbonate accumulations of other parts of carbonate horizons in the paleosols and background soils under irrigation. It was not possible to calculate the size and quantity of carbonates in those morphons because they were rare and had diffuse contours. Also, in the field we were not entirely sure that such morphons represent the initial paleosol properties or those formed under irrigation. At the same time, the morphological pattern of the humus horizon and its thickness in the paleosols buried in the third century AD of different study sites was very similar. Besides, in the upper horizons of the paleosol buried under BBK and paleosols buried under kurgans at the second-third centuries AD in the Brut 2 site, the morphological signs of solonetz properties (compact arrangement, shiny stress cutans on ped faces, columnar structure of soil mass) have been clearly expressed.

The most expressive and distinctive property in the paleosols buried at the approximate border between the fourth and fifth centuries AD of the Brut 1 and Brut 2 sites was the morphological pattern of humus infillings of root channels and mesofauna burrows that were observed within the upper 1.5–2 m of the soil profiles both in non-irrigated and irrigated paleosols.

The reconstructed humus content in the paleosol buried under BBK was higher and carbonate and gypsum content was lower than those in the background soil of the Beslan site (Fig. 3A, B, C). The maximum gypsum content in the paleosol (p.29b/03) is located deeper than that in the background soil (p.30m/03). The exchangeable Na content was slightly higher in the paleosol than that of the background soil of the Beslan site. On the whole, its content was not too high in these soils (Fig. 3D).

Comparing the analytical properties of the paleosols buried at the second–third centuries AD (p.20b/02, 21b/02, 25b/02) and the background soil (p.23m/03) of the Brut 2 site, it can be noted that the trends of humus content distribution in these paleosols (Fig. 4A) was rather similar to that in the Beslan site. Distribution of carbonate and gypsum in the soils of the Brut 2

Table 2
Morphological patterns of soil profiles studied in the Brut 1, Brut 2 and Beslan sites

Soils or chronointervals of paleosol burial	Description of morphological patterns of soil profiles	Profiles	Horizons	Depth, cm
The Brut 2 site				
All soils of the irrigated Brut 2 site	The predominance of gray and brown tints in color of humus horizons; CAs — white soft spots with diffuse shape in the Bk horizons; gypsum is absence within the profile			
The end of the second–the middle of the third centuries AD	The very weak pronounced tongue-like lower boundary of humus horizons; the coprogenic structure of the A1 horizon, the morphological solonetz properties in the uppermost part of profiles — compact arrangement, shiny stress cutans on ped faces, columnar structure of soil mass; rare "paleo-morphons" with large and well shaped white soft spots in the Bk horizons	20b/02, 21b/02, 25b/02, 27b/03	[A1] [ABk] [B1k] [B2k] [BCk]	0–55(60) 55–85(88) 85–110(112) 110–170 170–210
The approximate border between the fourth and fifth centuries AD	The morphological pattern of dark humus infillings of root channels and mesofauna burrows observed until 1.5–2 m depth of soil profiles and well preserved biogenic texture of soil mass; absence of morphological solonetz properties within the whole profile; the small and diffuse carbonate white soft spots with a halo of recrystallized carbonate around in the "paleo-morphons" of the Bk horizon	28b/03	[A1] [ABk] [B1k] [B2k] [BCk]	0–65(70) 65(70)–110 (115) 110(115)–150 150–180 180–210
The last quarter of the sixth–the beginning of the seventh centuries AD	The clearest tongue-like lower boundary of humus horizon in comparison with other soils in the chronosequence; the absence of dark humus infillings of root channels and mesofauna burrows in the middle and lower parts of profile; the quantity of carbonate white soft spots in the paleo-morphons of the Bk horizon was higher, the size of these CAs was smaller and the CAs had clearer contours as compared with those of the similar horizon in the paleosol buried at the border between the IVth and Vth centuries AD	31b/03	[A1] [ABk] [B1k] [B2k] [BCk]	0–60(65) 60(65)–80 80–120 120–170 170–200
Modern surface soil	The morphological pattern of dark humus infillings of root channels and mesofauna burrows observed until 1.5–2 m depth of soil profiles and well preserved biogenic texture of soil mass below the arable horizons (0–40 cm)	23m/02	A1 ABk B1k B2k BCk	0–60(70) 60(70)–100 100–130 130–170 170–200
The Beslan site				
All soils of the site Beslan	Black color of humus horizon; carbonate pseudomicellar forms (net of carbonate filaments) and white soft sports in the carbonate profile			
The third century AD	The weak pronounced tongue-like lower boundary of humus horizon, black color and coprogenic structure of humus horizon; the morphological solonetz properties (compact arrangement, shiny stress cutans on ped faces, columnar structure of soil mass) in the upper part of profile; abundance of carbonate pseudomicellar forms in the upper part of Bk horizon, the thickness of the layer with well shaped white soft sports is larger than that in the modern surface soils	29b/03	[A1] [ABk] [B1k] [B2k] [BCk]	0–60 60–90 90–120 120–150(160) 150(160)–200
Modern surface soil	The upper part of humus horizon (0–40 cm) is the arable horizon with uniform dark color and humus content, under the arable horizon there are the dark humus infillings of root channels and mesofauna burrows up to 1.5–1.7 m; the weak pronounced carbonate pseudomicellar forms in the upper part of Bk horizon and diffuse white soft spots — in the lower part of that horizon	30m/03	A1 ABk B1k B2k BCk	0–60(70) 60(70)–100 100–130 130–160(170) 160(170)–200
The Brut 1 site				
All soils of the site Brut 1	The black humus horizon with well pronounced coprogenic structure, the morphological pattern of dark humus infillings of root channels and mesofauna burrows observed until 1.5–2 m depth of soil profiles; the net of carbonate filaments (pseudomicellar forms of CAs) in the Bk horizon			
The border between the fourth and fifth centuries AD	The very weak pronounced net of carbonate filaments, the carbonate impregnation is predominated in the Bk horizon	13b/04	[A1] [ABk] [B1k] [B2k] [BCk]	0–70(75) 70(50)–110 110–140 140–170 170–200
The first half of the fifth century AD	The clear pronounced net of carbonate filaments (pseudomicellar forms of CAs) in the Bk horizon	2b/04, 32b/03, 9b/04, 10b/04, 11b/04, 12b/04, 14b/04	[A1] [ABk] [B1k] [B2k] [BCk]	0–70(75) 70(50)–110 110–140 140–170 170–200
Modern surface soil	The weak pronounced net of carbonate filaments in B1k horizon and of the humus infillings of root channels and mesofauna burrows in the horizons B2k and BCk	8m/04	A1 ABk B1k B2k BCk	0–75(80) 75(80)–120 120–150 150–180 180–200

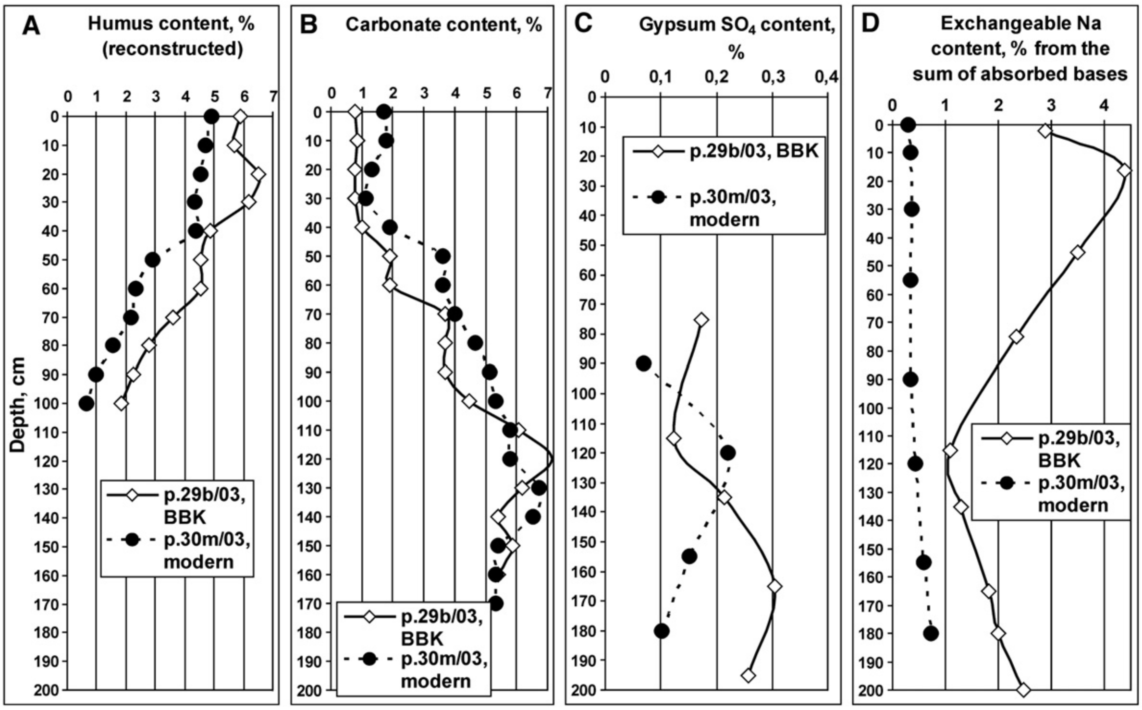

Fig. 3. Content of humus (A), carbonate (B), gypsum SO_4 (C), exchangeable Na from the sum of absorbed bases (D) in the paleosol (p.29b/03) and background soil (p.30m/03) of the Beslan site.

site was random: the carbonate content in the upper part of the paleosols of the second and third centuries AD was higher than those in the background soil (Fig. 4B), gypsum was absent within the uppermost 2 m of all the profiles (Fig. 4C). The exchangeable Na content was lower in the upper part than that in the medium and lowest parts of profiles in all of the irrigated paleosols of the Brut 2 site (Fig. 4D). At that, the morphological signs of solonetzicity were observed in the upper part of profiles

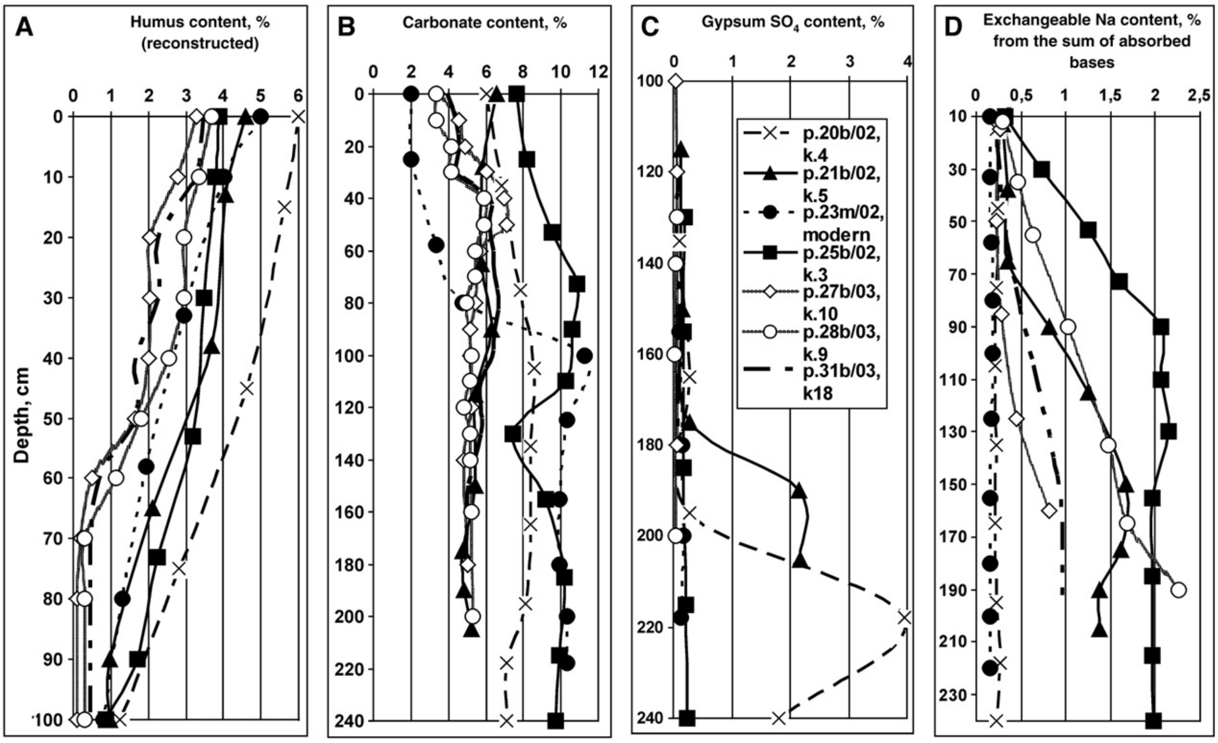

Fig. 4. Content of humus (A), carbonate (B), gypsum SO_4 (C), exchangeable Na from the sum of absorbed bases (D) in the paleosols and background soil of the site Brut 2.

Fig. 5. The excavation of the kurgans NN 9 and 10 in the Brut 2 site. 1 — the ditch around the kurgan N9; 2 — the ditch around the kurgan N10; 3 — the baulk of kurgan N10 and location of the p.27b/03; 4 — the baulk of kurgan N9 and location of the p.28b/03.

of those paleosols. The comparison of the distribution of the exchangeable Na content in the paleosol buried in the third century AD of the Beslan site with that of the even-aged paleosols of the Brut 2 site shows their difference: Na leaching in the medium and lower parts in the paleosols of Brut 2 occurred under the influence of irrigation. However, such distribution of the exchangeable Na content and the morphological signs of solonetzicity observed in the upper part of profiles in the paleosols of the Brut 2 site allowed us to propose that before irrigation the initial property of those soils was a higher content of the exchangeable Na in the upper horizons.

Thus, in spite of irrigation, we can conclude that some properties in the paleosols of the Brut 2 site seemed to be initial ones ("paleo-properties") and useful for paleoclimatic reconstruction. They include the morphological patterns of the humus horizon and humus content, the morphological signs of biological activity (humus infillings of root channels and mesofauna burrows) and solonetz properties. Sometimes, the morphological characteristics of carbonates preserved in few morphons of the carbonate horizon of the irrigated paleosols may be considered as initial properties if certain dissimilarity of such morphons with other part of the carbonate profile of the irrigated soils was observed. However we have never relied only on these morphons for the paleoclimatic reconstructions but interpreted them only in the context of other original paleosol properties. Based on the initial properties which were not changed under irrigation in the paleosols and background soil of the Brut 2 site, we were able to solve the second aim of our study, namely, to understand the initial properties changes in the soil chronosequences and to reconstruct the paleoclimatic conditions for the first centuries AD in this region of the Northern Caucasus.

The comparison of morphological patterns in the paleosols buried under kurgans N9 (p.28b/03) and N10 (p.27b/03) in the Brut 2 site provided strong evidence for the preservation of some initial properties in the paleosols after irrigation. Kurgan N10, constructed at the beginning of the third century AD, had a small mound and was covered by the larger mound of kurgan

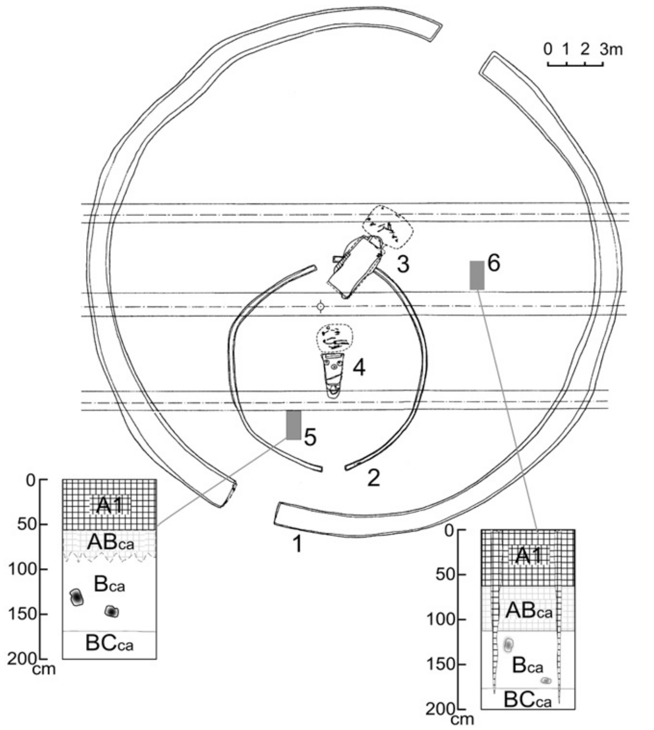

Fig. 6. The scheme of the relative position of the kurgans NN 9 and 10, ditches around the kurgans, baulks and pits 27b/03 and 28b/03 in the Brut 2 site. 1 — the ditch around the kurgan N9; 2 — the ditch around the kurgan N10; 3 — the central catacomb in the kurgan N9; 4 — the central catacomb in the kurgan N10; 5 — the location of the p.27b/03 near the central baulk of the kurgan 10; 6 — the location of the p.28b/03 near the central baulk of the kurgan 9.

N9 at the approximate border between the fourth and fifth centuries AD. The total thickness of these two mounds was about 40 cm (Table 1). During the excavation the edges (baulks) of the mounds of these two kurgans were situated at 5 m distance apart. At that, the pits, p.28b/03 and p.27b/03, situated near two baulks (Fig. 5) were significantly different. The humus infillings of root channels and mesofauna burrows were much better pronounced in the p.28b/03 than that in the p.27b/03 (Fig. 6). There were even humus infillings in a few vertical cracks in the lowest horizons of the p.28b/03 whereas in the cracks of similar horizons of the p.27b/03 the humus infillings were absent. Throughout the profile the humus content in the p.28b/03 was higher than that in the p.27b/03 (Fig. 4A). The carbonate white soft spots in the “paleo-morphons” of the Bk horizon in the p.27b/03 were large and had clear contours whereas those in the p.28b/03 were smaller and diffuse. The carbonate accumulations in the p.28b/03 were also surrounded by a thick halo of recrystallized carbonate.

In the paleosol, buried at the last quarter of the sixth–at the beginning of the seventh centuries AD in the Brut 2 site (kurgan N18, p.31b/03), the clearest tongue-like lower boundary of the humus horizon was observed unlike the other paleosols and the background soil of the Brut 2 site. The humus content in the pits 31b/03 and 27b/03 was lower than that in the pit 28b/03 (Fig. 4A). The quantity of carbonate white soft spots in the paleo-morphons of Bk horizon in the p.31b/03 was higher, the size of these carbonates was smaller and the carbonates had clearer contours as compared with those of the similar horizon in the p.28b/03.

Below we summarize the changes of the original pedogenetic properties in the paleosols of the Brut 2 site for the period from the end of the second to the beginning of the seventh centuries AD. In the paleosols buried in the end of the second and third centuries AD, relatively low humus content and absence of pronounced signs of biological activity, morphological signs of solonetzicity in the upper part of profiles and high content of exchangeable Na in the medium and lower parts of profiles, relatively large and clearly shaped carbonate white soft spots in the “paleo-morphons” of the Bk horizon were observed. At the same time in those paleosols very weak tongue-like lower boundary of humus horizons and the coprogenic structure in the A1 horizons were noted (Table 2). In the paleosol buried at the approximate border between the fourth and fifth centuries AD, relatively high humus content and clear signs of biological activity, absence of morphological and analytical signs of solonetzicity, diffused carbonate white soft spots in the “paleo-morphons” of the Bk horizon were noted. In the paleosol buried in the last quarter of the sixth–the beginning of the seventh centuries AD, relatively clear tongue-like lower boundary of humus horizon and decrease of humus content throughout the profile, signs of recrystallization and neoformations of carbonate white soft spots in the “paleo-morphons” of the Bk horizon were observed.

The paleosols of the non-irrigated and non-arable Brut 1 site enabled us to follow the changes of their properties for a relatively

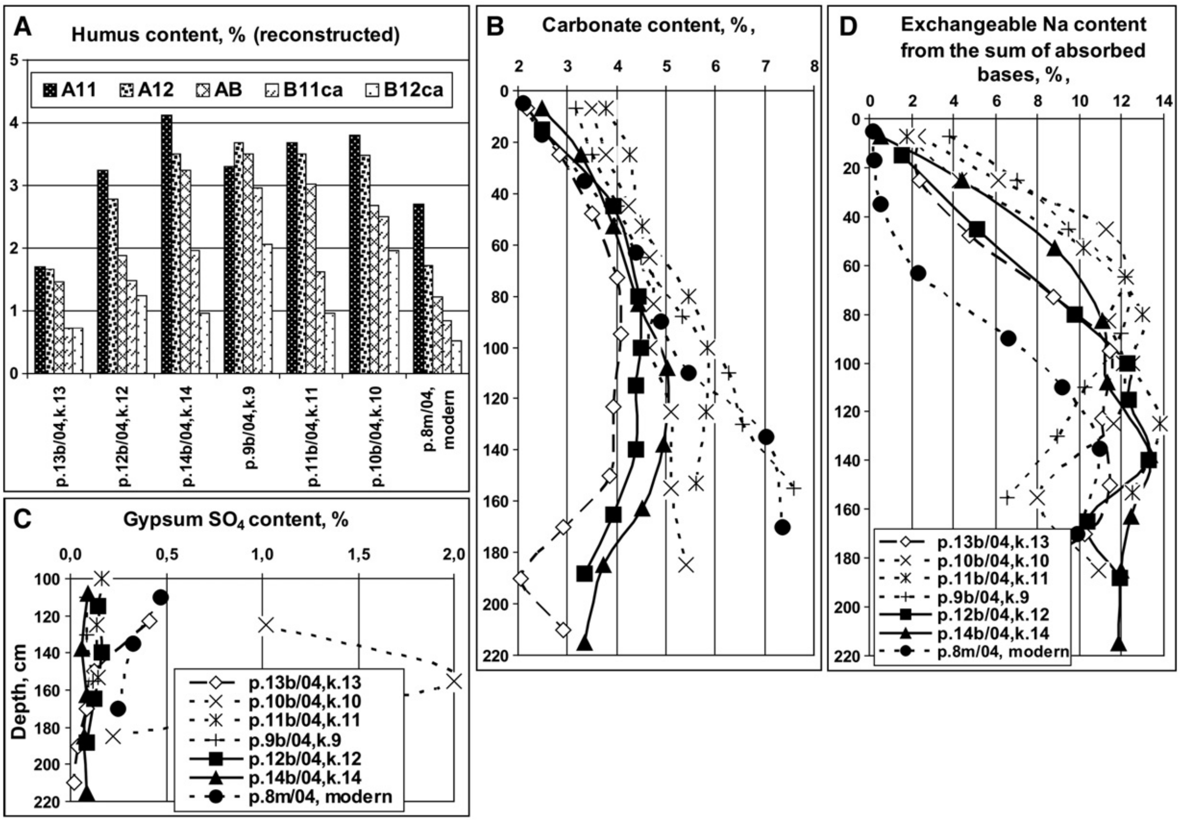

Fig. 7. Content of carbonate (B), gypsum SO_4 (C), exchangeable Na from the sum of absorbed bases (D) in the paleosols and background soil of the site Brut 1.

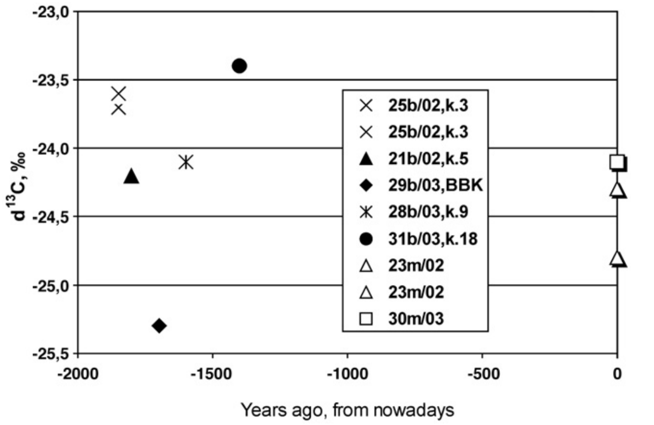

Fig. 8. Humus δ^{13}C values vs. dates of paleosols' burial (years ago, from nowadays).

short chronointerval — from the approximate border between the fourth and fifth to the middle of the fifth century AD. From the field morphological study, the differences in the carbonate profiles of paleosols were particularly evident. The carbonate accumulations in the upper horizons A1, AB and Bk of all the soils of the Brut 1 site were represented by the pseudomicellar forms that were completely absent in soils of the irrigated Brut 2 site.

From the paleosol buried at the approximate border between the fourth and fifth centuries AD (p.13b/04), an increase of density and thickness of the carbonate pseudomicellium (the net of carbonate filaments) in the paleosols buried at the first half of the fifth century AD has been observed. On the basis of that observation, the paleosols buried at the first half of the fifth century AD have been conventionally arranged in two groups. Pits 32b/03, 12b/04 and 14b/04 have been tentatively referred to the first group and the period of those paleosols burial is estimated to be the first quarter of the fifth century AD, whereas pits 2b/04, 9b/04, 10b/04, 11b/04 — to the second group with the period of burial during the second quarter of the fifth century AD. Hence, there are three groups of the paleosols buried at different times over the chronointerval from the approximate border between the fourth and fifth to the first half of the fifth centuries AD (an intercentennial soil chronosequence). From the paleosol buried in the approximate border between the fourth and fifth to those buried in the second quarter of the fifth century AD, in the intercentennial chronosequence the decrease of the intensity of the black color of humus infillings of root channels and mesofauna burrows has been noted.

With the exception of the minimum humus content throughout the uppermost meter in the p.13b/04 (Fig. 7A), there were no regularities in the data of humus content in the paleosols of the interdecadal chronosequence. This exception may be connected with the activity of the Early Alan people; that is, the burning of the area under the kurgans before a funeral was carried out. Archaeologists have noted this fact for the kurgan N13 of the Brut 1 site during excavation. Under a binocular microscope small pieces of charcoal have been observed until the depth of the Bk horizon (70–100 cm) in that pit. Hence, the low humus content in the p.13b/04 can be related with the pyrogenic impact on this soil before its burial. The clear trend of increasing of carbonate and exchangeable Na content in the upper part of profiles in the intercentennial chronosequence was noted (Fig. 7B, D). The gypsum SO_4 content was close to zero in all the paleosols of the Brut 1 site (Fig. 7C).

Finally, the data on humus isotopic composition in the paleosols and background soils in the Brut 2 and Beslan sites are shown in Fig. 8. The humus of paleosols, the earliest (p.25b/02, k.3, the end of the second–the beginning of the third centuries AD) and the latest (p.31b/03, k.18, the last quarter of the sixth – the beginning of the seventh centuries AD) based on the dates of their burial, showed the highest δ^{13}C values compared with other soils studied. These differences in humus δ^{13}C values cannot be interpreted by a shift of C_3–C_4 vegetation for the chronointerval studied, as the flora of the Northern Caucasus continued to be dominated by C_3-plants during the Holocene (Galushko, 1976). It is supposed to be a result of changes in humidity (Stevenson et al., 2005). Hence, the humus of the two paleosols mentioned above was formed in the driest climatic conditions as compared with the paleosols buried in other chronointervals and the background soils. This conclusion agrees well with data from the morphogenetic analysis of the soils in the chronosequence studied.

4. Conclusion

The changes of soil properties in the chronosequence studied let us reconstruct the paleoclimatic conditions of the first centuries AD for the Vladikavkazskaya depression in the Northern Caucasus. Stronger black color of humus horizon, increase of humus content and decrease of humus δ^{13}C values; clear signs of biological activity, absence of morphological and analytical signs of solonetz properties; diffused carbonate white soft spots in the Bk horizon and decreasing carbonate content are thought to be related with the comparatively humid climatic conditions in the region under study. On the contrary, relatively low humus content, tongue-like lower boundary of humus horizon, increase of humus δ^{13}C values, morphological signs of solonetz properties together with high content of exchangeable Na, relatively large and clearly shaped carbonate white soft spots in the paleosols of the Brut 2 site, as well as increase of density, thickness of the carbonate pseudomicellium and high carbonate content in the upper part of profiles in the paleosols of the non-irrigated Brut 1 site are assumed to be xeromorphic features, indicting comparatively drier climatic conditions.

The paleosols of the earliest chronointerval of burial (the end of the second–the beginning of the third centuries AD) demonstrate the clear xeromorphic properties developed under a relatively dry climate with mean annual precipitation 50–100 mm less than today. The estimated duration of a period with such climatic conditions is thought to be not less than 100 years. In addition, those paleosols demonstrate some signs of humid conditions indicating that at the border between the first and second or in the middle of the second century AD the climate started getting more moist, and mean annual precipitation became equal to that of today or slightly higher. At the approximate border between the fourth and fifth centuries AD, the next stage of drought-affected climate began and the paleosols buried in the first half of the fifth century AD demonstrate the gradual enhancement of xeromorphic properties.

The turning point in the direction of the paleosols' properties changing in the region for the first centuries AD has been determined more or less definitely on the basis of the study of the intercentennial chronosequence of paleosols buried at the narrow chronointerval — from the approximate border between the fourth and fifth to the middle of the fifth century AD. The paleosol buried at the last quarter of the sixth–the beginning of the seventh centuries AD in the site Brut 2 shows the most xeromorphic properties among all the paleosols studied. Thus, the period with favourable humid climate when the Early Alan culture flourished was relatively short (not more than 400 years duration) in the Holocene history of the Northern Caucasus.

The study of paleosols in the Brut 2 kurgan cemetery, which is influenced by the modern agrogenic activity including annual ploughing and intensive irrigation, showed that some initial properties ("paleo-properties") are preserved in those paleosols and may be used for paleoclimatic reconstruction. In order to distinguish initial and agrogenic properties in the paleosols the comparative approach has been applied. The background soils and paleosols of the Brut 2 site have been compared with synchronous soils of non-irrigated and, sometimes, non-arable Brut 1 and Beslan sites to detect pedogenic properties that are less changed by irrigation and thus comprise the "soil memory". These properties are: (1) the morphological patterns of the humus horizon, humus content and the data on humus isotopic composition, (2) the morphological signs of biological activity (humus infillings of root channels and mesofauna burrows), (3) solonetz properties and, (4) in some cases, the morphology of carbonate accumulations preserved in few morphons of the carbonate horizon of the irrigated paleosols.

The detailed chronosequence studied in the Brut 1 site permitted us to reveal the variability of paleosols properties in the intercentennial time scale (25–50 years) produced by comparatively "fast" pedogenic processes typical for the steppe zone: humus formation and accumulation, bioturbation, carbonate accumulation and transformation and solonetzization.

Acknowledgements

The Russian Foundation for Basic Researches supported this work (Grant Nos. 07-05-00905, 04-06-80044). We also would like to thank Sergey Sedov (Instituto de Geologia, UNAM, Mexico) for his help and assistance and our two reviewers, Vance Holliday (University of Arizona) and Emily McClung de Tapia (Instituto de Investigaciones Antropologicas, UNAM, Mexico), for their advices to improve the manuscript.

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